States and other universities should be framed by joint representatives of all our universities.

It would be a misfortune if anything in the nature of competitive schemes for attracting students were to be evolved independently by different university authorities.

J. B. COHEN.

Leeds, December 23.

The Deterioration of the Atmosphere in the Swiss Alps.

DR. MAURER, Director of the Swiss Federal Meteorological Service, sends a further communication about the deterioration of the atmosphere of the Swiss Alps, referring to Prof. Riccò's letter in NATURE of November 9 on the occurrence of an eruption at Stromboli. I am forwarding a translation for your information.

NAPIER SHAW.

Meteorological Office, South Kensington,
London, S.W., December 11.

This remarkable optical deterioration of the atmosphere was visible here (Zurich) until about the middle of November. The thin, cirrus-like layer could be seen on clear mornings just before sunrise at a height of about 14-15 km. above the earth's surface, according to our reckoning—that is to say, it was situated considerably above the usual cirrus region. It consisted of thin horizontal bands, extremely delicate and soft, which soon disappeared after sunrise. A curious fact was that no appreciable effect, either actinometric or photometric, was produced by this thin, mist-like layer. The impression made was that of a most delicate, comet-like veil of mist, yet not dimming the starlight. After sunrise absolutely nothing was to be seen of the phenomenon, in spite of the keenest observation through field-glasses of a weak magnifying power. Synchronising with this remarkable phenomenon, the sun had a large aureole with a diameter of 100°. Here and there the extreme outer edge of this ring was of a pale brown colour. So far we have not been able to offer any explanation as to the cause.

During the period of maximum visibility of the thin veil (twilight cirrus), such a conspicuous layer was to be seen in the eastern sky, shortly before sunrise and at a height of 40°, that even an unskilled observer would have noticed it at once. The structure of the layer was often so regular and definite in its remarkable horizontal stratification that it looked as though an artist with a coarse brush had coloured the whole eastern sky with long horizontal strokes not too neatly laid on.

Each time this peculiar veil of "twilight cirrus" reached a maximum of intensity we had a colourless morning twilight with interrupted "purple light." What can be the cause of all these remarkable phenomena?

Winter Thunderstorms.

A YEAR ago (December 16, 1915) I asked readers of NATURE if they would let me know when they observed thunder or lightning during the first three months of the year. I made a similar request to the observers of the British Rainfall Organisation. The number of replies I received amounted to nearly one thousand, and the rather remarkable fact came to light that during the period in question thunder or lightning occurred somewhere in the British Isles on sixty-four out of the ninety-one days. So numerous were the replies received that I was unable to answer each one personally, but I wish to thank those correspondents who kindly sent information, and to assure them that every report was of value.

The information obtained last winter was so remarkable, and the number of days on which thunder or lightning occurred so unexpected, that I am anxious to collect information again. Readers of NATURE could assist if they would send me a note by postcard or letter if they observe thunder or lightning between January 1 and March 31, 1917. The following points are of interest:—(1) Time when storm was nearest or overhead; (2) direction of storm when first observed, and time; (3) direction when last observed, and time; (4) note if there was a change of wind during the storm and if there was a drop in temperature; (5) any other information as to heavy rain, hail, snow, or any remarkable feature; (6) if an observer has accurate time, a list of the times of occurrence of flashes would be useful.

Many observers may not have the time or opportunity to record all these points, but I should be grateful for information on even one of them; No. 1 is the most important. The information is of real value, and every record, however short, is of use.

C. J. P. CAVE.

Meteorological Office, South Farnborough,
December 20.

GRAVITATION AND THE PRINCIPLE OF RELATIVITY.

ACCORDING to the principle of relativity in its most extended sense, the space and time of physics are merely a mental scaffolding in which for our own convenience we locate the observable phenomena of Nature. Phenomena are conditioned by other phenomena according to certain laws, but not by the space-time scaffolding, which does not exist outside our brains. As usually expressed, the laws of motion and of electrodynamics presuppose some particular measurement of space and time; but, if the principle is true, the real laws connecting phenomena must be independent of our framework of reference—the same for all systems of co-ordinates. Of course, it may be that phenomena are conditioned by something outside observation—a substantial æther which plays the part of an absolute frame of reference. But the following considerations may show that the ideal of relativity is not unreasonable. Every observation consists of a determination of coincidence in space or time. This is sufficently obvious in laboratory experiments; and even the crudest visual observation resolves itself into the coincidence of a light-wave with an element of the human retina. If, then, we trace the path of adventure of a material particle, it intersects in succession the paths of other particles or light-waves, and these intersections or coincidences constitute the observable phenomena. We can represent the course of Nature by drawing the paths of the different particles—on a sheet of paper in a two-dimensional case. The essential part of the diagram is the order of the intersections; the paths between the intersections are outside observation altogether, and are merely interpolated. The sequence of phenomena will not be altered if the paper is made elastic and deformed in any way, because the serial order of the intersections is preserved. This deformation of the paper corresponds to a mathematical transformation of the space in which for convenience we have located the phenomena.

Until recently the application of the principle of relativity was limited to one particular transformation, namely, a uniform translation of the axes. In this case there is a wide range of experimental evidence in support of the principle. In 1915 Prof. A. Einstein[1] finally succeeded in developing the complete theory by which the postulate of relativity can be satisfied for all transformations of the co-ordinates. Gravitation plays a part of great importance in the new theory, and therein lies much of the practical interest of Einstein's work.

No attempt is made to explain the cause of gravitation—as a kink in space or anything of that nature. But the extended law of gravitation is determined, to which Newton's law is an approximation under ordinary conditions. It has long been suspected that there must be some modification of the law when the bodies concerned are in rapid relative motion; moreover, the "mass" of a moving body no longer has a unique meaning, so that a further definition, if not extension, of Newton's law is clearly needed. Now, although we do not seek a *cause* of gravitation in the properties of space, it may well happen that the *law* of gravitation is determined by these properties. The inverse-square law represents the natural weakening of an effect through spreading out in three dimensions; we may say that it is determined by the properties of Euclidean space. There is, therefore, nothing unreasonable in proceeding, as Einstein does, to examine whether a more extended law is suggested by the properties of generalised space—that is, by geometry.

The way in which gravitation enters into the discussion may be seen from the following example. Suppose an observer is in a closed lift; let the supports break and the lift fall freely. To the observer everything in the lift will now appear to be without weight; gravity has been suddenly annihilated. The acceleration of his frame of reference (the lift) is equivalent to an alteration of the gravitational field. Now an acceleration of the axes is one of the transformations contemplated by the general principle of relativity, and it is therefore necessary to allow that the gravitational field depends on the choice of co-ordinates. There is a "local" gravity, just as there is a "local" time or magnetic field depending on the co-ordinates selected.

We can now take a brief survey of Einstein's procedure. Suppose that space and time are measured by a system of co-ordinates x_1, x_2, x_3, x_4; x_4 is the time, but there is no need to discriminate between it and the others. If there is a gravitational field at any point, it can be abolished (as in the example of the lift) by choosing new co-ordinates x_1', x_2', x_3', x_4' accelerated with respect to the old. The necessary transformation could be specified in various ways; the way chosen involves the element of length *ds*, measured by coincidences with a standard scale, and therefore independent of the choice of co-ordinates. Since in the x' co-ordinates there is no gravitation to complicate matters, we can safely use the usual formula,

$$ds^2 = dx_1'^2 + dx_2'^2 + \dots$$

and this when transformed to the old co-ordinates takes the most general form,

$$ds^2 = g_{11}dx_1^2 + g_{22}dx_2^2 + \dots + 2g_{12}dx_1dx_2 + 2g_{13}dx_1dx_3 + \dots$$

The ten g's depend on the transformation, and can be used to specify it. But they do more than that; they define the original gravitational field, since they specify how it can be got rid of. They usually vary from point to point, because a different transformation is needed to eliminate gravity at different points. In the new theory the g's are regarded as ten gravitational potentials specifying the field; and, in fact, one of them, g_{44}, is approximately the same as the Newtonian potential ϕ, except for a factor.

The inverse-square law can be expressed by the well-known differential equation $\nabla^2\phi = 0$. Evidently the new law of gravitation must be a generalisation of this—an equation, or set of equations, involving the ten potentials instead of one. Also, to conform to relativity, the new equations must be unaltered by a change of co-ordinates. If new co-ordinates are used the g's will be different, but the relations between the new g's and new co-ordinates must be the same as those between the old g's and old co-ordinates. The possible sets of relations which satisfy this are very limited in number. This subject, known as the theory of tensors, has been worked out very fully by Riemann, Christoffel, and others, and the possible sets of equations can be classified and enumerated. From this limited choice we have further to pick out a set of equations which will reduce to $\nabla^2 g_{44} = 0$ as a first approximation, and that is found to leave only one possibility. There is just one set of ten differential equations (of which, however, only six are independent) which satisfy both conditions. Einstein takes these as expressing his generalised law of gravitation. It is important to notice exactly how much of this is geometry. Geometry shows that *if* the equations hold for a particular set of co-ordinates, they hold for every set. We abolish the "if," and so assert a new law of Nature.

It is further necessary to consider what must be the generalised equivalent of Poisson's equation $\nabla^2\phi = -4\pi\rho$, which supplants Laplace's equation when matter is present. The extension is not difficult, since it is found that the ten equations above mentioned are the expression of a generalised principle of least action as applied to gravitational energy. Now mass is considered to be simply electromagnetic energy, and since there is no reason to believe that electromagnetic energy will behave differently from gravitational energy in regard to least action, we have only to include both forms of energy together in the equations, treating them as equivalent. It is not possible to write down here these final equations, since a very elaborate notation is needed for their expression.

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[1] Einstein, "Die Grundlage der allgemeinen Relativitätstheorie." (Leipzig: J. A. Barth, 1916.) A detailed account appears in *Monthly Notices*, 1916, No. 9, by Prof. W. de Sitter, giving the astronomical applications. See also an article by de Sitter in the *Observatory*, October, 1916.

Though highly complicated in form, they can be applied without excessive labour to the more simple problems.

One or two of the more elementary consequences of this theory were given by Einstein some years ago. A ray of light must be bent in passing through an intense field of gravitation; thus a star seen close to the limb of the sun during an eclipse should appear displaced 1·7″ from its usual position. The vibrations of an atom must be slower in an intense field, so that the lines of the solar spectrum should be displaced slightly to the red as compared with terrestrial spectra. It has not yet been possible to put these predictions to a satisfactory test, and it has been left to the completed theory to furnish the first opportunity of an appeal to observation. In this the new theory has scored a most signal success, for it has cleared up the most celebrated case of discordance in gravitational astronomy.

From his generalised law of gravitation Einstein has deduced that the elliptic orbit of a planet will rotate in the direction of motion at the rate of

$$\frac{24\pi^3}{V^2}\frac{a^2}{T^2(1-e^2)} \text{ radians per revolution of the planet.}$$

Here V is the velocity of light, and a, T, e are the semiaxis, period, and eccentricity of the orbit. If v is the velocity of the planet, the amount is practically $6\pi v^2/V^2$ radians per revolution. For Mercury this works out at 43″ per century—just the amount of the outstanding discordance between observation and theory. The theory also gives rotations for Venus and the earth, but their orbits are so nearly circular that the effect is imperceptible to observation. For Mars, with its strongly elliptic orbit, the correction is more important, and sensibly improves the accordance between theory and observation.[2]

It is rather difficult to grasp the fact that the same laws of Nature may hold when some bizarre system of co-ordinates is chosen. Suppose an observer A uses rectangular co-ordinates, and B, through some kink in his mind, uses polar co-ordinates without realising that he is doing anything unusual. For A a ray of light can travel along the straight line x = constant; but evidently it cannot travel along the circle r = constant, which is B's idea of a straight line. The answer is that B through his peculiar system of measurement will suppose that he is in an intense gravitational field; he will calculate the curvature in the ray of light produced by this field; and, making allowance for it, he will find that the light actually travels along its theoretical curve (*i.e.* curve for B, but straight line for A). Thus the same general laws of Nature are satisfied for B as well as for A; and it might be difficult to decide which of them had got hold of the absolute rectangular co-ordinates.

A. S. EDDINGTON.

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[2] The discordance of the perihelion of Mercury (now removed) was nearly 30 times its probable error. Of the sixteen secular variations of the four inner planets, all are now accordant, except the node of Venus, which deviates by $4\frac{1}{2}$ times its probable error. Among sixteen residuals we should expect to find one of three times the probable error, so that the evidence for the remaining discordance is not very strong. There are besides unexplained variations of the longitudes of the moon and planets, but these are in a different category.

PLANTS IN HEALTH AND DISEASE.[1]

PROF. WEISS and his colleagues have done well in publishing in book-form abstracts of their lectures on Plants in Health and Disease. The lectures were delivered at the University of Manchester during 1915-16, and had for their object the giving of botanical guidance to the many small gardeners and allotment-holders who were, and are, endeavouring by the cultivation of their several plots to add to the food supplies of the country.

Although only its friends recognise the fact, science in this country suffers from the virtue of modesty. Accompanying that quality—as is so often the case—is often a certain hauteur. Hence it is that those who—only too rarely, it must be confessed—come seeking guidance from science are often sent empty away. It would be well for science, and also for the country, if this attitude of aloof detachment were to cease to be habitual. It is true that biological science has at present not overmuch to offer to horticulturists; but that is an added reason why closer relations should be established between those who cultivate the land and those who study the science of biology. It is by such means as those adopted by Prof. Weiss and his colleagues that this contact may be best established.

It is no adverse criticism on this little book to say that if and when science and practice go hand in hand a thoroughly good botany for gardeners will make its appearance, and not before. One of the results of such a book will be to teach the gardener to do scientifically and better what he now does empirically and well. The day of publication of that perfect book is far off, and botany will have not only to grow but to be pruned very heavily before it is written. The science will have to cast off the pseudo-encyclopædic habit, woven in Germany, which it wears. For example, when talking to gardeners of the importance of restricting water supply in order to provoke flower and fruit formation (p. 2), why not give an account of the current method of tomato-growing instead of citing examples from "tropical climes"? In the cultivation of the tomato the check imposed after the first truss of fruit is set, the pinching-out of side-shoots, the stopping of the leader, and the reduction of leaf surface, all have for their purpose the regulation of the water supply and the reduction of vigour of vegetative growth. Apart, however, from the fact that those who are habitually engaged in gardening might not infrequently suggest more cogent illustrations of botanical principles, the general account given in these lectures of the life of a plant is admirable. Occasionally we discover a lapse, as, for example (p. 7), the omission to mention the chief virtue of the hoe, namely, that by its use water is conserved in the soil.

The less difficult parts of the book, those which

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[1] "Plants in Health and Disease: being an Abstract of a Course of Lectures delivered in the University of Manchester (1915–16)." By Prof. F. E. Weiss, Dr. A. D. Imms, and Wilfrid Robinson. Pp. 143. (Manchester: At the University Press; London: Longmans, Green and Co. 1916.) Price 1*s.* 6*d.* net.